Design and Application of Intelligent Monitoring System for Aluminium Smelter Multifunctional Overhead Crane

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Abstract

Aluminium production through electrolysis relies on overhead cranes and traditional overhead crane monitoring systems have such problems as signal attenuation and fault response delays in harsh environments like high temperatures, dust, and strong magnetic fields, which affects production efficiency and equipment stability. This paper proposes an intelligent monitoring system that is based on wireless bridge redundancy transmission, AI visual analysis, and PLC networking with an aim to enhance the operational stability and maintenance efficiency of the overhead cranes used at aluminium smelters. This system uses the dual-link redundancy technology to provide a certain guarantee for the high reliability of wireless communication. Furthermore, the combination of AI visual monitoring and fault diagnosis algorithms enables real-time fault predication and precise maintenance to a certain extent. In addition to providing a feasible path for the intelligent upgrading of aluminium smelters, this system can have its performance further optimized through the integration of 5G edge computing and digital twin technologies.

Keywords: Aluminium smelter, Overhead crane monitoring, Wireless communication.

1. Introduction

1.1 Research Background

Aluminium smelters are a typical example of heavy industrial facilities. Their multifunctional overhead cranes operate in extremely complex environments for a long time, with temperature inside potrooms rising up to 70 ±5 °C in high-temperature areas during summer while dropping to -25 °C in low-temperature areas during winter, accompanied by high-concentration pollution caused by alumina dust, carbon particles, and hydrogen fluoride gas. The strong magnetic fields generated by aluminium reduction pots (300 G at crane railways level and 800 G at anode busbars level) pose severe challenges to the anti-interference capability of electronic equipment. Traditional overhead crane monitoring systems often have problems due to severe signal attenuation and fault response delays under these conditions. Existing wireless communication networks suffer from insufficient signal coverage due to the shielding effects of potrooms' steel structures and the electromagnetic interference from aluminium reduction pots, rendering the overhead crane's PLC control system offline for extended periods. Furthermore, the hardware loosening caused by mechanical vibrations and sensor failures resulting from high-temperature and dust exposure further destabilize the system, making it difficult to meet the mandatory requirements for real-time data acquisition and safety interlocks specified in China's national standard Regulation on Safety Technology for Lifting Appliances ref. TSG 51–2023.

References [1–5] give more detailed background information on modern developments of overhead cranes.

1.2 Questions Raised

Nowadays, the overhead crane monitoring system of aluminium smelters faces three core defects:

(1) Insufficient communication stability.
Due to the weak penetration of 5 GHz frequency band, the existing wireless access point (AP) has severe signal blind zones in potroom buildings with a long span of 1 140 meters. The packet loss probability of single-link transmission is as high as 12 %, and PLC data has not been integrated into the network, resulting in the delay of more than 45 minutes in fault information transmission.

(2) Weak data integration capability.
Multi-source heterogeneous data (such as hoisting weight, brake status and video stream) lacks a unified processing platform and it is impossible to achieve accurate diagnosis of 165 types of faults.

(3) Insufficient environmental adaptability.
Traditional cameras can have a resolution attenuation of 40 % at a high temperature of 70 °C and encoders can experience an accuracy deviation of up to ±2.5 % in strong magnetic fields, severely compromising system reliability. These issues result directly in an average of 8 hours of unplanned shutdown per month and an 18 % increase in annual maintenance costs. To that end, there is an urgent need to develop an intelligent monitoring system that integrates redundancy communication, AI visual analysis and predictive maintenance to break through the existing technical bottlenecks and meet the demands of efficient operations and maintenance in the era of Industry 4.0.

1.3 Technical Route

This intelligent monitoring system uses a three-tier architecture to perform intelligent overhead crane monitoring at aluminium smelters: The DB-MESH dual-link redundancy technology is deployed in the wireless communication layer, operating at 5 GHz to achieve 860 Mbps transmission rate, and supporting dual-link synchronous data transmission and seamless switching (packet loss probability < 0.1 %). The data acquisition layer integrates high-protection hardware including Hikvision cameras with IP66 protection, anti-magnetic absolute encoders (precision ±0.5 %), and PLC networking modules, enabling real-time acquisition of 165 types of data from 18 overhead cranes, such as hoisting weight, braking status and operating trajectories. The intelligent analysis layer incorporates AI visual algorithms, using 2-megapixel cameras to achieve high pedestrian recognition accuracy and analysing current peak-to-peak variations to build predictive maintenance models so as to issue 24-hour advance warnings for such faults as motor blockage. The system uses an end-to-end fibre optic backbone network (3 km transmission distance) and the server in the central control room consolidates multi-source data, enabling global visual monitoring through Web/APP platforms.

1.4 Significance of Research

(1) Theoretical significance.
To address the technical bottlenecks in electromechanical equipment monitoring systems in extreme industrial environments, an intelligent monitoring framework that integrates redundancy communication and multimodal perception is established. A dynamic anti-interference transmission mechanism is proposed for industrial IoT architecture design, providing new theoretical support for studying the reliability of wireless communication in high electromagnetic field environments. The multi-source heterogeneous data fusion method of AI vision and electromechanical signals expands the theoretical boundaries of industrial equipment fault

5.2 Limitations

While the system demonstrated excellent communication stability and data processing capabilities, accuracy degradation still existed in some sensors under the extreme magnetic field conditions (reaching up to 800 G at the pot anode busbars). Field measurements showed measurement errors of ±1.2 % for the absolute encoders and current transformers, primarily were caused by the interference from the strong magnetic fields on the current induction of metal materials. Additionally, high temperatures (70 °C) and dust (PM10 ≥ 200 μg/m^3) posed challenges to camera durability, with the lens coating of some devices suffering from aging after continuous operation for 12 months. In the future, the anti-magnetic shielding design of the sensors and the selection of high-temperature resistant materials need to be further optimized to enhance reliability throughout their entire lifecycle.

5.3 Future Directions

Building on the existing system architectures and engineering practices, future research will focus on technological integration and collaborative optimization. The integration of 5G edge computing and digital twin technology will significantly enhance system real-time performance. By deploying edge computing nodes, data processing delay can be reduced from 15 ms to under 5 ms. The high-precision simulation of overhead cranes with the help of digital twin models will enable a breakthrough of 98 % in fault prediction accuracy. Cross-plant data collaboration will rely on the Help library module to establish a distributed knowledge-sharing platform, integrating multi-plant fault case libraries and maintenance strategy libraries and supporting semantic-matching-based intelligent decision suggestions. Research on high-temperature resistant and anti-magnetic materials can reduce sensor accuracy degradation, for example, ceramic matrix composites can be used to replace the traditional metal sensing units. The development of adaptive lightweight AI algorithms will enhance model robustness under dynamic operating conditions, reducing dependence on high-performance computing hardware.

6. References

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